COTTON

Variability in Cotton Fiber Yield, Fiber Quality, and Soil Properties in a Southeastern Coastal Plain

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ABSTRACT

To maximize profitability, cotton (*Gossypium hirsutum* L.) producers must attempt to control the quality of the crop while maximizing yield. The objective of this research was to measure the intrinsic variability present in cotton fiber yield and quality. The 0.5-ha experimental site was located in a producer's field (Norfolk–Coxville soil association) in Florence, SC, for 2 yr (1996 and 1997). Soil (0–20 cm) and fiber samples (1-m row) were collected from a regular grid (129.2 by 45.6 m, 7.6-m interval). Soil properties determined included soil moisture, soil texture, organic matter, pH, Ca, Mg, K, P, and Na. Fiber quality was estimated by the high-volume instrumentation method and the Advanced Fiber Information System. Fiber strength and elongation were also estimated by the stelometer procedure. All fiber and soils data were analyzed by both nonspatial statistics and geostatistical techniques. Distinct patterns of spatial correlation were observed in soils and fiber yield. These patterns were not equally evident in all fiber properties. Soil pH, soil P, and soil organic matter were correlated with fiber yield and a number of fiber properties, including micronAFIS, immature fiber fraction, fine fiber fraction, cross-sectional area, and micronaire. Factor analysis of soil properties identified four factors in 1996 and three in 1997. In both years, a *Carolina bay* factor and an *exchangeable bases* factor were obtained. These factors were not successfully related to fiber yield and quality. Kriged contour maps of soil properties provided useful indicators of fiber yield and quality variation.

Precision agriculture is an information- and technology-based agricultural management system that identifies, analyzes, and manages site spatial and temporal variability within fields for optimum profitability, sustainability, and protection of the environment (Robert et al., 1995, 1996). Recent developments in cotton yield-sensing technology (Wilkerson and Hart, 1996) and soil-fertility mapping (Valco et al., 1998) indicate that precision agriculture systems show potential for widespread use in cotton production. In addition, several studies have demonstrated that the spatial variability of cotton yield and fiber quality is sufficient to justify site-specific management. In a study performed in Winnsboro, LA (Johnson et al., 1999), the authors found that cotton yield and all fiber quality properties measured, with the exception of short-fiber content, displayed spatial correlation. They also noted that fiber yield was correlated with soil organic matter, B, Cu, Fe, Mn, and Zn. Fiber quality was correlated with soil Mg, K, Cu, and As. Elms et al. (1997) reported that yield in an irrigated cotton field in Texas displayed spatial correlation. These authors also noted that production of fruiting sites and fruit retention was spatially correlated. Micronaire exhibited a moderate degree of spatial variability, and strength showed the lowest degree of variability.

Several recent publications have attempted to quantify the extent of soil spatial variability present in soils of the Southeastern Coastal Plains. Sadler et al. (1995) attempted to relate crop yield variations to soil map unit but found that intramap unit variance was almost as large as intermap unit variance. This variation was not successfully explained using statistical regression methods or mechanistic modeling. Geostatistical techniques provided a better description of the high- and low-yield regions, but year-to-year variation obscured some of the underlying trends. This problem was addressed by normalizing yield before the kriging procedure. Sadler et al. (1998) reported that crop yields in Southeastern Coastal Plain soil were correlated with soil map unit, but the relation was weak at best. Crop yields also displayed spatial correlation with a range varying from 57 to 252 m. However, it was noted that significant variation occurred at distances as short as 10 m, suggesting that a modification of current soil- and plant-sampling schemes might prove necessary and more appropriate for precision agriculture applications.

Precision agriculture offers cotton producers a management strategy that could help to control production inputs so that return is maximized. Although absolute quantities of crop inputs may not be decreased, the reallocation of these inputs could result in better utilization and decreased waste (Olson, 1998). The objective of this study was to measure soil variability in relation to both cotton fiber yield *and* quality in a field under typical commercial crop management.

MATERIALS AND METHODS

Soils

A field experiment conducted in a producer's field in Florence, SC, investigated the influence of soil spatial variability

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Abbreviations: AFIS, Advanced Fiber Information System; A(n), fiber cross-sectional area by number; CEC, cation exchange capacity; CV, coefficient of variation; FFF, fine-fiber fraction; Hunter's +b, yellowness; HVI, High-Volume Instrumentation; IFF, immature fiber fraction; L(hvi), fiber length as determined by high-volume instrumentation; L(n), fiber length by number; L(w), fiber length by weight; Rd, reflectance; SFC(n), short fiber content by number; SFC(w), short fiber content by weight.

on the variability of cotton 'LA 887', fiber yield and quality. Several soil types of the Norfolk–Coxville soil association were present in the experimental site. These soils included a Marlboro sandy loam (fine, kaolinitic, thermic Typic Paleudults), a Coxville fine sandy loam (fine, kaolinitic, thermic Typic Paleaquults), and Norfolk fine sandy loam (fine-loamy, kaolinitic, thermic Typic Kandiudults). Soil samples (0–20 cm) and seed cotton (1-m row) were collected from a regular grid (129.2 by 45.6 m, 7.6-m interval). A total of 102 grid points were sampled in 1996 and 101 in 1997 (one missing sample). The grid location was chosen to include a Carolina bay landform to achieve a representative range in soil and fiber variability. The predominant soil in the Carolina bay was a Coxville fine sandy loam, and the Marlboro sandy loam was the major soil type in the remaining section of the field. Soil properties determined for both years included soil moisture, organic matter, pH, Ca, Mg, K, P, Na, and cation exchange capacity (CEC). Organic matter was determined by Walkley–Black wet oxidation [Nelson and Sommers (1982)] and soil pH by a 1:1 soil/water ratio in deionized water. Ions were extracted with 1 *M* ammonium acetate, pH 7.0, and analyzed by inductively coupled plasma spectroscopy (ICP). Soil texture was determined on the 1996 samples by the pipette method of Miller and Miller (1987).

Fiber

In October, seed cotton samples were collected, by hand, from approximately 1 m of row centered on the grid points. Seed cotton from small, immature bolls that would not be harvested by commercial spindle pickers was not harvested. Seed cotton was saw-ginned and weighed to determine yield. The bulk fiber samples were then subsampled to determine fiber quality. Several methods were employed to evaluate fiber quality. The Zellweger Advanced Fiber Information System (AFIS, Zellweger Uster, Knoxville, TN) was used on all samples, and the high-volume instrumentation (HVI) method and stelometer procedure were used when the fiber sample weight was $\geq$50 g. This decreased the total number of samples analyzed for the stelometer and HVI procedure to 85 in 1996 and 79 in 1997. Each procedure provides valuable insight into the inherent fiber quality of a given sample. The HVI method is the standard fiber quality classification method used by the Agricultural Marketing Service to grade all commercially grown cotton in the USA. The AFIS method is used primarily by cotton researchers and provides several additional indices of fiber maturity compared with the HVI method. It also has the important advantage of requiring a smaller sample size. Finally, the stelometer procedure is an additional index of fiber bundle strength and elongation that is used by textile processors. Fiber properties determined by the AFIS system included fiber length by number [L(n)] and weight [L(w)], short-fiber content (percentage distribution of fibers $<$12.5 mm) by weight [SFC(w)] and number [SFC(n)], diameter by number, theta (circularity), immature fiber fraction (percentage distribution of theta < 0.25), cross-sectional area by number, fine-fiber fraction (FFF, percentage distribution of fiber with cross-section $< 60\ \mu m^2$), micronAFIS (micronaire analog), and perimeter. Properties determined by the HVI method include micronaire, length, elongation, uniformity, strength, leaf grade (a measure of leaf residue in the fiber), and color as estimated by the degree of reflectance (Rd) and yellowness (Hunter's +b). Fiber strength and elongation percentage were also determined by the stelometer method.

Data Analysis

Exploratory and descriptive analyses were performed using conventional univariate statistics (SAS PROC UNIVARIATE, SAS Inst., Cary, NC) and variogram analysis (SAS PROC VARIOGRAM and GS+, Gamma Design Software, Plainwell, MI). Before variogram analysis, 3D surface plots were constructed for each variable (SAS PROC GRID, PROC 3D). This information was used to determine the strategy for variogram analysis. When an obvious linear trend existed in the variable, spatial data were detrended by fitting a plane surface through each data set (SAS PROC REG), evaluating the surface at each data point, and subtracting the surface from the raw data (Sadler et al., 1998). Where linear trends were apparent, the direction of the major trend variation appeared to be on the longitudinal axis, with a maximum response in the area of the predominant Carolina bay. Exceptions to this effect were observed for sand in 1996 and fiber +b in 1997. For other variables, a bimodal effect was apparent in the data, and it was not possible to fit a simple linear trend. In this case, a decreased search neighborhood was utilized to construct variograms by limiting the maximum lag distance used in the analysis. It was the opinion of the authors that this bimodal effect was caused by a change in soil type that occurred in the longitudinal direction. Both of these procedures were used to account for the apparent nonstationarity present in the experimental site. An underlying assumption of the sample variogram is that of a constant mean with the covariance function dependent only on the distance separating the points, not the direction (Kitanidis, 1997). The presence of a trend in the data or the aforementioned bimodal behavior would question these assumptions.

The soil and fiber data sets were combined for the 1996 and 1997 growing seasons, and correlation analysis was performed (SAS PROC CORR) in an attempt to relate soil and fiber properties. It was the authors' opinion that combining the data sets would allow for a more complete investigation of the long-term relations between soil and fiber properties. Pearson's correlation coefficients were determined for all soil and fiber combinations. There was some concern as to the cross correlation of soil properties. For this reason, an attempt was made to use factor analysis to group the soil properties and then relate them to fiber yield and quality. Principle-component factor analysis, with an orthogonal varimax rotation, was utilized to extract the factors. The factor analysis was performed on the correlation matrix to eliminate the effect of the soil properties' different measuring units. The varimax rotation redistributes the variance of each variable in an attempt to have the variable load high on only one factor (Brejda, 1998). In addition, contour plots were constructed of selected soil and fiber properties using ordinary kriging (Surfer, Golden Software, Golden, CO) and the previously determined theoretical variograms. All plots included in the study were subjected to variogram analysis with a decreased search neighborhood and not detrended.

The influence of the Carolina bay on soil and fiber properties was investigated by categorizing all samples as to their position in the field (within or outside of the Carolina bay). The difference between these areas was then tested for significance by the Wilcoxon test (SAS PROC NPAR1WAY). This is a nonparametric test that evaluates differences between sample medians (Steel and Torrie, 1980). This approach was used to address concerns related to the equality of variances within and outside of the bay.

RESULTS AND DISCUSSION

Soil Properties

Univariate Statistics

Soil property data from the 1996 and 1997 growing seasons is presented in Table 1. During the 1996 growing

Table 1. Univariate statistics for soil properties for 1996 and 1997 cotton field experiment, Florence, SC.

Soil property	*N*	Mean	Median	SD	CV	Skewness	Kurtosis	Norm.†
				1996				
Soil moisture, %	102	19.7	18.9	3.9	19.7	2.1	10.4	0.74***
P, mg kg^{-1}	102	158.8	111.4	116.8	73.6	1.0	−0.27	0.84***
Na, mg kg^{-1}	102	5.9	5.8	1.9	31.7	0.40	−0.29	0.97*
K, mg kg^{-1}	102	142.9	139.4	45.3	31.7	0.30	−0.84	0.97**
Ca, mg kg^{-1}	102	217.3	205.4	73.3	33.7	0.61	−0.22	0.96**
Mg, mg kg^{-1}	102	49.5	46.3	16.1	32.5	0.86	0.40	0.94***
Soil pH	102	5.2	5.3	0.48	9.1	−0.33	−0.96	0.95***
Organic matter, %	102	0.86	0.6	0.54	62.8	1.1	0.004	0.81***
CEC‡, cmol$_c$ kg^{-1}	102	1.6	1.5	0.57	35.6	0.42	−0.58	0.97*
Sand, %	102	71.7	76.8	15.2	21.2	−1.25	0.36	0.82***
Silt, %	102	23.1	16.8	13.7	59.3	1.19	0.12	0.81***
Clay, %	102	5.2	4.0	3.6	68.5	0.65	0.39	0.93***
				1997				
Soil moisture, %	102	9.1	8.5	1.9	21.0	1.1	0.37	0.88***
P, mg kg^{-1}	102	161.8	109.5	119.3	73.7	1.1	−0.13	0.84***
Na, mg kg^{-1}	102	6.3	6.1	1.9	30.6	0.82	1.01	0.95***
K, mg kg^{-1}	102	145.4	140.6	45.0	31.0	0.37	−0.95	0.95***
Ca, mg kg^{-1}	102	251.4	242.9	78.8	31.3	1.1	2.39	0.93***
Mg, mg kg^{-1}	102	56.3	50.6	18.2	32.4	0.52	−0.63	0.95**
Soil pH	102	5.0	5.1	0.53	10.6	−0.22	−0.57	0.96**
Organic matter, %	102	0.82	0.54	0.50	61.5	1.3	0.37	0.80***
CEC, cmol$_c$ kg^{-1}	102	2.1	2.0	0.60	28.4	0.55	−0.47	0.95**

* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.001 level.
† Shapiro–Wilkes statistic (*W*) for normal distribution. Significant *W* indicates that data is not normally distributed.
‡ CEC, cation exchange capacity.

season, the majority of these properties exhibited a positive skew, with the mean greater than the median. Soil pH exhibited a slight but measurable negative skew, as did the percentage sand content. A relatively small degree of kurtosis was exhibited by all properties, with the greatest effect seen in the soil moisture data. The coefficients of skewness and kurtosis values describe the shape of the sample distribution. A positive skew indicates asymmetry in the distribution, with the higher data values tailing to the right, and a negative skew represents lower values tailing left. Kurtosis describes the relative size of the distribution's tails. A positive coefficient of kurtosis indicates that the distribution is peaked, and a negative value indicates a relatively flat distribution. Taken together, these values describe the conformity of the data to a normal distribution. The coefficients of variation (CVs) for the properties measured ranged from 9.1% for pH to almost 74% for soil P (Table 1). The properties exhibiting the greatest variability included P, clay, organic matter, and silt contents. All soil properties investigated exhibited non-normal distributions.

During the 1997 growing season, a similar effect was observed in the soil data, with all properties exhibiting a positive skew, except for soil pH, which again exhibited a slight but measurable negative skew. There was no pronounced degree of kurtosis observed for any of the measured soil properties. The CVs for the 1997 data set were very similar to the 1996 data set, with the coefficients varying from 10% for soil pH to almost 74% for soil P (Table 1). The properties that exhibited the greatest variability were also similar. As in 1996, all soil properties exhibited non-normal distributions. The degree of variability observed in the soil properties suggests that a site-specific management strategy would prove beneficial for this location.

Spatial Variability

The spatial correlation present in the soil data will be summarized using variograms. The variogram measures the average dissimilarity between data points separated by a given distance (Goovaerts, 1997). The graphical variogram provides a summary of measured spatial structure of a given property within the experimental location. The experimental variogram, which is computed from the data, is usually described or *fit* to a theoretical variogram model (Kitanidis, 1997). Important features of the variogram include the range, sill, and nugget. The *range* is the maximum distance at which spatial correlation is observed. This is the distance at which the variogram plot exhibits a plateau. The *sill* is the value that corresponds to the range distance (or plateau). The variogram exhibits a *nugget effect* if a discontinuity (from zero) is present at the origin (Isaaks and Srivastava, 1989). Sampling error and short-scale variability often cause these measurable deviations. The lower the variogram values are for distance lags less than the range, the stronger the spatial correlation.

All soil properties, except soil moisture in 1996, displayed spatial correlation at some distances. After examination of the preliminary variograms, it was apparent that several of the properties required detrending (the mean varied along the *x* or *y* gradient). This was indicated by a variogram that did not exhibit a sill (i.e., continued to increase with distance). The properties that required detrending included soil P, soil organic matter, sand content, and silt content (Table 2). After the detrending process, the variograms for these properties showed more conventional spatial structure with distinct sills and ranges of spatial correlation. For variables not exhibiting a trend, a separate evaluation of the range of spatial correlation was required. For several of these

Table 2. Soil semivariance parameters for 1996 and 1997 cotton field experiment, Florence, SC.

Property	Pretreat†	Maxlag‡	Model§	Sill	Range	Nugget	r^2
		m			m		
			1996				
Soil moisture, %	NS	–		–	–	–	–
P, mg kg^{-1}	D	80	S	8690	68.6	10.0	0.968
Na, mg kg^{-1}	ND	100	E	4.019	79.8	2.009	0.878
K, mg kg^{-1}	ND	50	S	2595	41.7	1.00	0.979
Ca, mg kg^{-1}	ND	50	S	7178	41.6	10.00	0.994
Mg, mg kg^{-1}	ND	50	S	345.7	42.2	5.00	0.998
Soil pH	ND	100	S	0.347	99.0	0.002	0.996
Organic matter, %	D	80	S	0.1818	52.3	0.0004	0.997
CEC¶, cmol$_c$ kg^{-1}	ND	50	S	0.378	33.0	0.011	0.998
Sand, %	D	50	S	100.01	44.3	0.10	0.990
Silt, %	D	50	S	78.51	45.9	0.10	0.992
Clay, %	ND	50	S	14.84	37.0	1.72	0.993
			1997				
Soil moisture, %	D	80	S	2.108	36.8	0.106	0.955
P, mg kg^{-1}	D	80	S	8285	67.0	10.0	0.964
Na, mg kg^{-1}	ND	50	S	4.42	46.6	1.654	0.994
K, mg kg^{-1}	ND	50	S	2732	39.9	1.00	0.961
Ca, mg kg^{-1}	ND	50	S	7599	33.8	510.0	0.984
Mg, mg kg^{-1}	ND	50	S	404.9	34.5	1.00	0.995
Soil pH	ND	100	S	0.412	83.2	0.021	0.990
Organic matter, %	D	80	S	0.1322	52.2	0.0001	0.971
CEC, cmol$_c$ kg^{-1}	ND	50	S	0.461	35.4	0.001	0.987

† Data set pretreatment: D = data set detrended by fitting plane surface, subtracting trend, and performing variogram analysis on residuals; ND = not detrended; NS = not spatially correlated.
‡ Maximum lag distance used in variogram fitting.
§ Proposed theoretical variogram model: E = exponential; S = spherical.
¶ CEC, cation exchange capacity.

properties, a bimodal variogram was obtained in the preliminary analysis. This effect was attributed to the contrasting soil types surrounding the Carolina bay landform present in the experimental site. It might have been possible to model this variogram with a *hole effect* model, a type of model that introduces a pseudo-periodicity to the covariance function and that has been used in hydrology (Kitanidis, 1997). Instead, a more direct strategy was adopted. The maximum lag distance (beyond which pairs of points were not included) for the empirical variogram was reduced; hence, the hole effect was eliminated. This procedure also circumvented difficulties associated with nonstationarity of the means from the various areas within the experimental site, a problem discussed in the Methods section.

All of the soil properties investigated were described with the spherical variogram model, with the exception of soil Na in 1996, which was described by the exponential model (Table 2; Fig. 1). It should be noted that the range parameter reported for the exponential model is, in fact, an effective range. This is equal to the distance at which 95% of the sill is achieved and is estimated as three times the fitted range parameter (Robertson, 1998). The ranges of spatial correlation in 1996 varied from 33 m for CEC to 99 m for soil pH. Similar results were obtained for 1997, with ranges extending from 34 m for soil Ca to 83 m for soil pH. The soil basic cations Ca, Mg, and K exhibited a similar spatial response in both 1996 and 1997, with ranges of spatial correlation from 34 to 42 m. These responses were also observed for CEC (which is the sum of basic cations) and soil texture. The variograms for these properties exhibited the bimodal behavior discussed earlier. It is postulated that this effect is related to the varying soil types surrounding the Carolina bay landform. The soils within the bay are finer textured, with greater silt contents, than those immediately surrounding the bay where the soils are coarser in texture. At greater distances, the soils become finer once again. This variation in soil texture is also related to concurrent increases in soil organic matter and soil nutrient content. The range of spatial correlation for soil organic matter in both 1996 and 1997 was approximately 52 m. Soil P and Na had slightly larger ranges, with values of 69 and 80 m in 1996 and 67 and 47 m in 1997, respectively. Finally, soil pH exhibited the greatest range of spatial correlation in both years, with values of 99 and 83 m, respectively.

Fiber Properties

Univariate Statistics

Fiber yield and quality data from the 1996 and 1997 growing seasons are presented in Tables 3 and 4, respectively. In 1996, the cotton yield data exhibited a very slight positive skew, with the mean in good agreement with the median (Table 3), and possessed a normal distribution. The CV, however, was significant (52.3%), reflecting the large range in the data. The majority of fiber properties were normally distributed, with the means in good agreement with the medians and with relatively low skewness and kurtosis values. Exceptions included FFF, fiber +b, and elongation by stelometer and HVI. The CVs for measured fiber properties ranged from 1.7% for fiber uniformity to 20.1% for FFF (Table 3). The properties with the highest variability were FFF, immature fiber fraction (IFF), SFC(w), micronAFIS, and micronaire, with CVs of 20.1, 14.8, 10.9, 10.2, and 9.2%, respectively.

The yield data for the 1997 growing season were

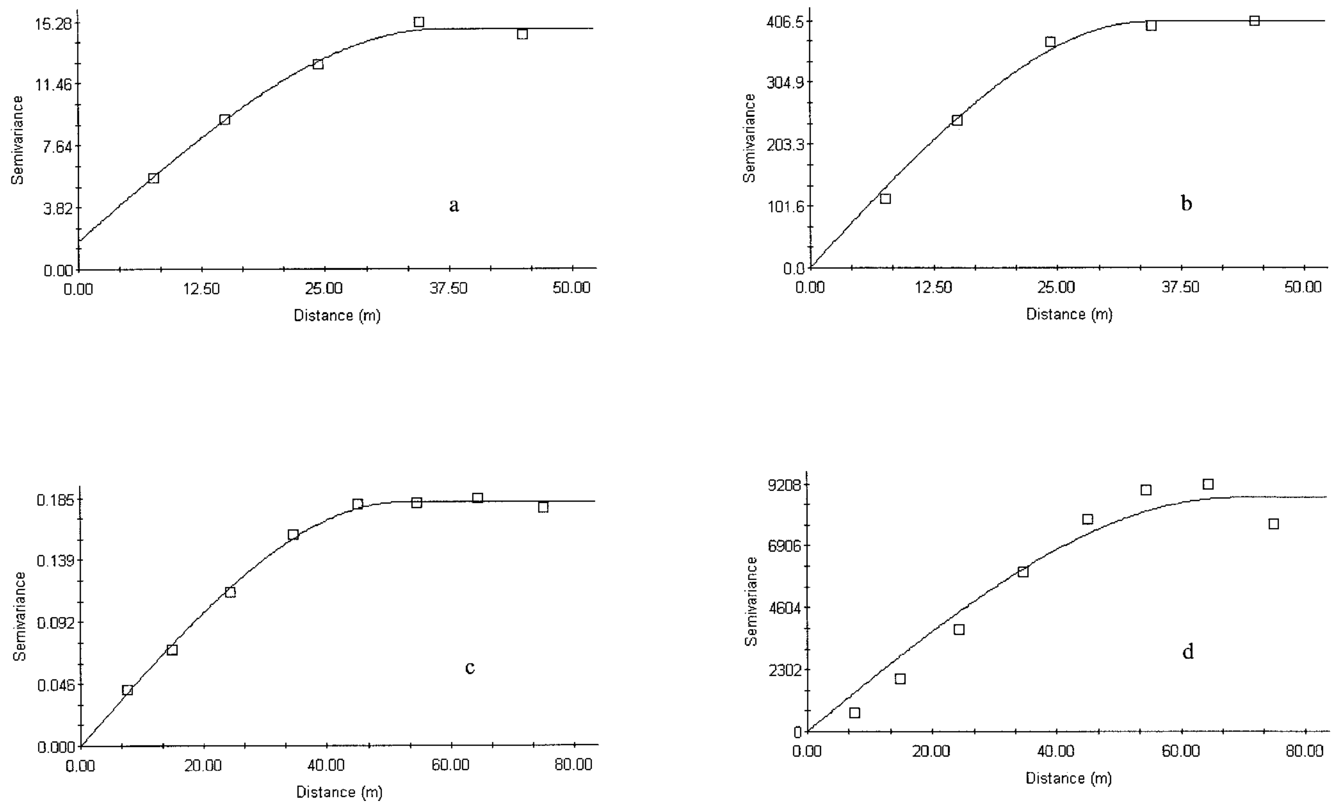

Fig. 1. Variograms for (a) soil clay content (%) in 1996, (b) soil Mg (mg kg^{-1}) in 1997, (c) soil organic matter (%) in 1996, and (d) soil P (mg kg^{-1}) in 1996.

slightly lower than the results from the previous year (Table 4). The data again showed a small positive skew, with the mean close to the median and a normal distribution. The CV (43.0%), although reduced from 1996, was still significant. As in the 1996 data, the majority of 1997 fiber properties were normally distributed, with close agreement between mean and median and small skewness and kurtosis values. Exceptions were for L(n), fiber length as determined by HVI [L(hvi)], uniformity, Rd, and elongation by stelometer and HVI. The CVs for the fiber properties were also similar to those obtained for the 1996 growing season, with CV values ranging

Table 3. Univariate statistics for fiber properties for 1996 cotton field experiment, Florence, SC.

Fiber property†	*n*	Mean	Median	SD	CV	Skew	Kurtosis	Norm.‡
Yield, kg ha^{-1}	102	851.8	853.3	445.3	52.3	0.35	−0.16	0.98 ns
L(w), mm	102	23.5	23.4	0.67	2.8	0.24	−0.03	0.98 ns
SFC(w), %	102	8.9	8.8	0.97	10.9	0.19	−0.005	0.99 ns
L(n), mm	102	19.7	19.6	0.60	3.1	0.20	−0.01	0.98 ns
SFC(n), %	102	23.1	22.9	1.9	8.3	−0.08	−0.30	0.99 ns
D(n), μm	102	13.3	13.3	0.62	4.7	−0.22	0.21	0.99 ns
Theta	102	0.46	0.46	0.02	4.8	−0.15	0.05	0.98 ns
IFF, %	102	14.5	14.4	2.2	14.8	0.37	−0.08	0.98 ns
A(n), μm^2	102	106.8	107.0	6.7	6.3	−0.11	0.007	0.99 ns
FFF, %	102	18.2	17.8	3.7	20.1	0.80	0.53	0.95**
MicronAFIS	102	3.8	3.8	0.39	10.2	0.01	0.09	0.99 ns
Perimeter, μm	102	53.9	53.9	0.98	1.8	0.02	1.14	0.98 ns
Strength (stlmtr), kN m kg^{-1}	85	255.8	257.0	11.34	4.4	0.08	−0.29	0.98 ns
Elongation (stlmtr), %	85	7.36	7.50	0.50	6.8	−0.70	0.48	0.93***
Micronaire	85	3.8	3.8	0.35	9.2	−0.10	0.37	0.98 ns
L(hvi), mm	85	28.3	28.2	0.64	2.8	−0.49	0.20	0.97 ns
Uniformity, %	85	82.1	82.0	1.4	1.7	−0.12	−0.82	0.97 ns
Strength (hvi), kN m kg^{-1}	85	279.7	280.6	13.50	4.8	−0.06	−0.53	0.99 ns
Elongation (hvi), %	85	6.3	6.3	0.25	4.0	−0.45	0.95	0.95**
Rd	85	76.9	76.9	1.73	2.3	−0.14	−0.29	0.98 ns
+b	85	8.83	8.80	0.61	6.9	0.43	1.97	0.97*

* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.001 level.
† L(w), fiber length by weight; SFC(w), short fiber content by weight; L(n), fiber length by number; SFC(n), short fiber content by number; D(n), diameter by number; IFF, immature fiber fraction; A(n), fiber cross-sectional area by number; FFF, fine-fiber fraction; stlmtr, stelometer; L(hvi), fiber length as determined by high-volume instrumentation; hvi, high-volume instrumentation; Rd, reflectance; +b, yellowness.
‡ Shapiro–Wilkes statistic (*W*) for normal distribution. Significant *W* indicates that data is not normally distributed.

Table 4. Univariate statistics for fiber properties for 1997 cotton field experiment, Florence, SC.

Fiber property†	*n*	Mean	Median	SD	CV	Skew	Kurtosis	Norm.‡
Yield, kg ha^{-1}	101	714.6	734.3	307.1	43.0	0.29	0.31	0.98 ns
L(w), mm	101	23.8	23.9	0.76	3.2	0.13	−0.31	0.98 ns
SFC(w), %	101	7.8	7.8	0.88	11.3	0.22	0.04	0.99 ns
L(n), mm	101	20.1	20.1	0.69	3.4	0.21	−0.51	0.97*
SFC(n), %	101	20.9	21.1	1.7	7.9	0.11	0.27	0.99 ns
D(n), μm	101	13.5	13.6	0.59	4.3	0.39	−0.07	0.98 ns
Theta	101	0.48	0.48	0.03	7.2	0.26	−0.33	0.98 ns
IFF, %	101	12.8	12.9	2.6	20.2	0.10	−0.30	0.99 ns
A(n), μm^2	101	110.6	110.0	7.8	7.0	0.39	0.18	0.99 ns
FFF, %	101	15.5	15.6	3.3	21.0	0.22	−0.11	0.99 ns
MicronAFIS	101	4.1	4.0	0.54	13.2	0.36	−0.03	0.99 ns
Perimeter, μm	101	53.9	53.8	0.90	1.7	0.35	−0.31	0.99 ns
Strength (stlmtr), kN m kg^{-1}	79	222.6	220.7	11.74	5.3	0.27	−0.17	0.98 ns
Elongation (stlmtr), %	79	6.71	6.70	0.15	2.2	0.27	0.16	0.95**
Micronaire	79	3.95	3.90	0.40	10.1	0.25	−0.35	0.98 ns
L(hvi), mm	79	28.5	28.7	0.93	3.3	−0.41	−0.43	0.96*
Uniformity, %	79	83.3	83.4	1.2	1.4	−1.0	2.0	0.93***
Strength (hvi), kN m kg^{-1}	79	291.0	292.3	15.26	5.2	0.004	0.89	0.98 ns
Elongation (hvi), %	79	6.6	6.6	0.35	5.3	−1.15	2.50	0.92***
Rd	79	76.5	76.5	1.61	2.1	−0.37	2.39	0.96*
+b	79	9.6	9.6	0.59	6.1	0.23	0.08	0.98 ns

* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.001 level.
† L(w), fiber length by weight; SFC(w), short fiber content by weight; L(n), fiber length by number; SFC(n), short fiber content by number; D(n), diameter by number; IFF, immature fiber fraction; A(n), fiber cross-sectional area by number; FFF, fine-fiber fraction; stlmtr, stelometer; L(hvi), fiber length as determined by high-volume instrumentation; hvi, high-volume instrumentation; Rd, reflectance; +b, yellowness.
‡ Shapiro–Wilkes statistic (*W*) for normal distribution. Significant *W* indicates that data is not normally distributed.

from 1.4% for fiber uniformity to 21% for FFF (Table 4). It should be noted that the fiber properties with the highest variability were identical to those noted in the 1996 growing season. Fine-fiber fraction, IFF, micronAFIS, SFC(w), and micronaire again exhibited the highest variability, with coefficients of 21.0, 20.2, 13.2, 11.3, and 10.1%, respectively. These fiber properties are all strongly influenced by environmental variations and may benefit from site-specific management techniques.

Spatial Variability

The yield and fiber properties variogram analyses from the 1996 and 1997 growing season are presented in Tables 5 and 6, respectively, and in Fig. 2. In contrast to the soil property data, several of the fiber properties did not exhibit any spatial correlation. In many cases, the variograms exhibited a pure nugget effect, indicating that the variability was not affected by distance (Fig. 2d). In 1996, these properties included cotton yield, SFC(w), SFC(n), strength and elongation by stelometer and HVI,

Table 5. Cotton fiber semivariance parameters for 1996 cotton field experiment, Florence, SC.

Property†	Pretreat‡	Maxlag§	Model¶	Sill	Range	Nugget	r^2
		m			m		
Yield, kg ha^{-1}	NSC	–	–	–	–	–	–
L(w), mm	ND	100	S	0.252	39.00	0.221	0.862
SFC(w), %	NSC	–	–	–	–	–	–
L(n), mm	ND	100	S	0.2028	51.9	0.1908	0.769
SFC(n), %	NSC	–	–	–	–	–	–
D(n), μm	D	50	S	0.3452	26.9	0.1526	0.982
Theta	D	50	S	0.00044	15.1	0.00008	0.771
IFF, %	D	50	S	3.821	13.5	0.753	0.720
A(n), μm^2	D	50	S	40.16	24.3	14.54	0.975
FFF, %	D	50	S	11.73	24.3	5.86	0.976
MicronAFIS	D	50	S	0.1324	19.0	0.0252	0.909
Perimeter, μm	D	50	E	0.823	6.4	0.232	0.922
Strength (stlmtr), kN m kg^{-1}	NSC	–	–	–	–	–	–
Elongation (stlmtr), %	NSC	–	–	–	–	–	–
Micronaire	ND	100	S	0.1266	13.6	0.0218	0.500
L(hvi), mm	ND	100	S	0.00107	40.2	0.00053	0.830
Uniformity, %	NSC	–	–	–	–	–	–
Strength (hvi), kN m kg^{-1}	NSC	–	–	–	–	–	–
Elongation (hvi), %	NSC	–	–	–	–	–	–
Rd	NSC	–	–	–	–	–	–
+b	NSC	–	–	–	–	–	–

† L(w), fiber length by weight; SFC(w), short fiber content by weight; L(n), fiber length by number; SFC(n), short fiber content by number; D(n), diameter by number; IFF, immature fiber fraction; A(n), fiber cross-sectional area by number; FFF, fine-fiber fraction; stlmtr, stelometer; L(hvi), fiber length as determined by high-volume instrumentation; hvi, high-volume instrumentation; Rd, reflectance; +b, yellowness.
‡ Data set pretreatment: D = data set detrended by fitting plane surface, subtracting trend, and performing variogram analysis on residuals; ND = not detrended; NSC = not spatially correlated.
§ Maximum lag distance used in variogram fitting.
¶ Proposed theoretical variogram model: E = exponential; S = spherical.

Table 6. Cotton fiber semivariance parameters for 1997 cotton field experiment, Florence, SC.

Property†	Pretreat‡	Maxlag§	Model¶	Sill	Range	Nugget	r^2
		m			m		
Yield, kg ha^{-1}	ND	50	S	99 000	24.1	41 900	0.887
L(w), mm	NSC	–	–	–	–	–	–
SFC(w), %	NSC	–	–	–	–	–	–
L(n), mm	NSC	–	–	–	–	–	–
SFC(n), %	NSC	–	–	–	–	–	–
D(n), μm	ND	50	S	0.3698	18.3	0.1224	0.978
Theta	ND	50	S	0.00125	31.3	0.00028	0.996
IFF, %	ND	100	S	7.057	28.1	2.28	0.947
A(n), μm^2	ND	100	S	63.20	22.6	13.2	0.798
FFF, %	ND	50	S	11.22	18.4	3.76	0.913
MicronAFIS	ND	50	S	0.3144	29.8	0.0677	0.977
Perimeter, μm	ND	100	E	0.8160	6.2	0.234	0.737
Strength (stlmtr), kN m kg^{-1}	ND	100	S	114.3	20.4	27.5	0.822
Elongation (stlmtr), %	NS	–	–	–	–	–	–
Micronaire	ND	50	S	0.1632	12.6	0.0311	0.549
L(hvi), mm	ND	50	E	0.00135	5.4	0.00036	0.651
Uniformity, %	NSC	–	–	–	–	–	–
Strength (hvi), kN m kg^{-1}	NSC	–	–	–	–	–	–
Elongation (hvi), %	ND	100	S	0.1422	86.6	0.0706	0.835
Rd	ND	100	E	2.746	10.6	0.599	0.636
+b	D	100	E	0.2202	6.4	0.0626	0.523

† L(w), fiber length by weight; SFC(w), short fiber content by weight; L(n), fiber length by number; SFC(n), short fiber content by number; D(n), diameter by number; IFF, immature fiber fraction; A(n), fiber cross-sectional area by number; FFF, fine-fiber fraction; stlmtr, stelometer; L(hvi), fiber length as determined by high-volume instrumentation; hvi, high-volume instrumentation; Rd, reflectance; +b, yellowness.

‡ Data set pretreatment: D = data set detrended by fitting plane surface, subtracting trend, and performing variogram analysis on residuals; ND = not detrended; NSC = not spatially correlated.

§ Maximum lag distance used in variogram fitting.

¶ Proposed theoretical variogram model: E = exponential; S = spherical.

fiber uniformity, Rd, and fiber +b. In the 1997 season, these included L(w), L(n), SFC(w), SFC(n), elongation by stelometer, fiber uniformity, and strength by HVI. This is not surprising as many of these fiber length properties have a strong genetic link that is modulated by relatively small responses to the growth environment. It should be noted that variability in these fiber properties that occurred at a distance less than the 7.5-m sampling interval would not be captured in the analysis. However, the remaining fiber properties, which are re-

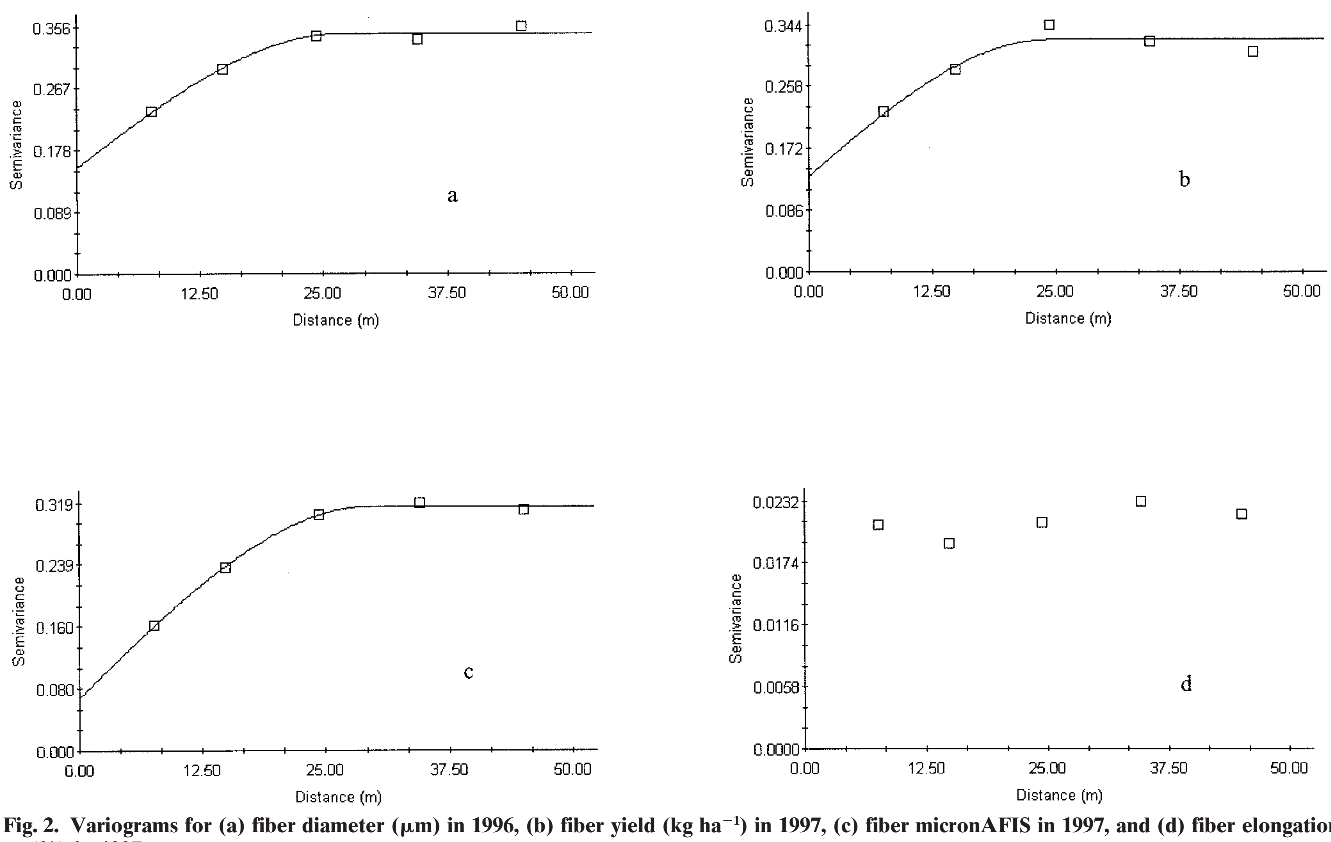

Fig. 2. Variograms for (a) fiber diameter (μm) in 1996, (b) fiber yield (kg ha^{-1}) in 1997, (c) fiber micronAFIS in 1997, and (d) fiber elongation (%) in 1997.

lated to fiber maturity, and therefore more strongly influenced by the growth environment, were spatially correlated. As with the soil properties, a spatial trend was observed in some fiber properties, leading to detrending before variogram analysis. In 1996, this included diameter by number, theta, IFF, cross-sectional area by number, FFF, micronAFIS, and perimeter. In 1997, only fiber +b required detrending. The majority of the variograms were described with the spherical model in both years, with the exponential model being utilized for the remaining cases.

In the 1996 growing season, fiber length as determined by the AFIS method, i.e., L(n) and L(w), and as determined by the HVI method, L(hvi), were all found to be spatially correlated. The ranges of spatial correlation for these properties were similar: values of 39 m for L(w) and L(hvi) and 51.9 m for L(n) (Table 5). Micronaire, which is an unitless index of fiber fineness and maturity obtained from HVI analyses, had a range of spatial correlation of approximately 14 m in 1996 (Table 5). MicronAFIS, which is the AFIS analog to micronaire, had a slightly larger range of 19 m for the 1996 season (Table 5). The remaining fiber properties exhibiting spatial correlation in the 1996 season are all AFIS maturity and shape indices. It is interesting to note that these properties appeared to have similar spatial tendencies, all requiring detrending and all with a maximum lag distance of 50 m. The AFIS maturity properties include theta, IFF, FFF, and micronAFIS. The range of spatial correlation for these properties varied from 13.5 m for IFF to 24 m for FFF (Table 5). The AFIS shape properties, diameter by number and cross-sectional area by number, had similar ranges of 27 and 24 m, respectively. Finally, fiber perimeter, although spatially correlated, had a relatively small range of 6 m. The variogram for fiber perimeter was also the only case in which the exponential model was employed (Table 5).

During the 1997 growing season, a slightly different picture of fiber property spatial variability was obtained. Cotton yield was spatially correlated with a range of 24 m (Table 6). Fiber length, as determined by the AFIS procedure, did not exhibit spatial correlation, and L(hvi) was only weakly correlated, with a range of 5 m (Table 6). The range for micronaire (13 m) was similar to that found in 1996, and the micronAFIS range (30 m) was slightly larger. The AFIS maturity and shape properties were all spatially correlated. The ranges for theta and IFF doubled in 1997 compared with 1996, and the FFF range decreased (Table 6). The ranges for fiber area and diameter both decreased in 1997, compared with 1996, and the perimeter ranges in the two years were approximately the same. Several additional fiber properties exhibited spatial correlation in 1997 compared with 1996. Fiber strength, as estimated by the stelometer method, had a range of 20 m, and elongation percentage from the HVI analyses had the longest range observed with 87 m (Table 6). Finally, the HVI color indices of Rd and +b were both spatially correlated, with ranges of 11 and 6 m, respectively. Although differences in the spatial variability of the fiber properties did occur between the two years, several trends are apparent in the data.

Fiber micronaire exhibited spatial correlation in both years, with a range of 13 to 14 m. While this range is considerably smaller than ranges observed for some of the other fiber properties, it still represents a significant distance in the field, and it would be sufficient to enable precision management techniques. When the micronaire values are outside the band from 3.5 to 4.9, a monetary penalty is assessed to the producer. Thus, precision management of micronaire may be economically expedient. Both the AFIS shape and maturity properties were spatially correlated in both years. Although the ranges varied slightly between years, similarities were apparent.

Relation between Soil and Fiber Variability

Correlation Analysis

Results from the correlation analysis between soil and fiber properties from the combined 2-yr data set are presented in Table 7. Soil texture was not included in this table because it was only analyzed in the 1996 samples. Fiber yield was significantly correlated to soil P, organic matter, pH, CEC, K, and Na. The negative correlation to P and organic matter is related to the increase in these properties in the Carolina bay present in the field. This part of the field was subject to flooding during periods of high rainfall, resulting in significant decreases in yield. The soil pH was also lower in this region, accounting for the significant positive correlation. The strongest observed linear relationship with fiber length was with soil moisture, with the negative correlation indicating that shorter fibers will occur in the wetter parts of the field. Significant positive correlations were also observed with Ca and Mg. Diameter was best described by soil pH, P, and organic matter. Theta, IFF, cross-sectional area by number, FFF, and micronAFIS are all related to fiber maturity and exhibited similar responses to soil variation. The strongest relationship with these properties appears to be soil pH, followed by soil P and organic matter. Soil moisture and soil Mg also influenced these properties but to a lesser extent. Fiber properties determined by the HVI method include micronaire, length, uniformity, strength, elongation percentage, Rd, and +b. These properties were most strongly correlated with soil moisture and soil P, but significant correlations were also observed with soil pH and organic matter. Fiber +b responded somewhat differently, with significant correlations with soil Ca, Mg, and CEC. Fiber Rd was also correlated with soil Na and K. Fiber properties determined by the stelometer method included strength(s) and elongation(s). Both of these properties were strongly correlated ($r = 0.70$ and $r = 0.56$, respectively, both significant at the 0.001 level) with soil moisture and, to a lesser extent, with soil pH and organic matter. This effect is somewhat puzzling because negative correlations were obtained for the HVI estimates of strength and elongation. These combined observations suggest that fiber yield and quality

Table 7. Pearson's correlation coefficients between soil and fiber properties for combined (1996 and 1997) data set.

Fiber property†	Moist.	P	Na	K	Ca	Mg	pH	OM‡	CEC§
Yield, kg ha^{-1}	ns	−0.51***	−0.14*	−0.17*	ns	ns	0.46***	−0.50***	−0.18*
L(w), mm	−0.21***	−0.21**	ns	ns	0.23***	0.25***	0.23**	−0.17*	ns
SFC(w), %	0.40***	ns	ns	−0.18**	−0.28***	−0.23***	ns	ns	−0.26***
L(n), mm	−0.32***	ns	ns	0.16*	0.27***	0.27***	ns	ns	0.17*
SFC(n), %	0.40***	ns	ns	−0.20**	−0.26***	−0.21**	ns	ns	−0.31***
D(n), μm	−0.14*	0.36***	ns	ns	−0.16*	−0.28***	−0.46***	0.32***	ns
Theta	−0.19**	0.35***	ns	ns	ns	−0.15*	−0.46***	0.27***	ns
IFF, %	0.23***	−0.36***	ns	ns	ns	0.15*	0.48***	−0.30***	ns
A(n), μm^2	−0.17*	0.40***	ns	ns	−0.15*	−0.25***	−0.51***	0.33***	ns
FFF, %	0.28***	−0.31***	ns	ns	ns	0.20**	0.45***	−0.25***	ns
MicronAFIS	−0.18*	0.39***	ns	ns	ns	−0.20**	−0.51***	0.31***	ns
Perimeter, μm	ns	0.14*	ns	ns	ns	−0.22**	−0.17*	0.15*	ns
Strength (stlmtr), kN m kg^{-1}	0.70***	ns	ns	ns	ns	ns	0.27***	ns	−0.27***
Elongation (stlmtr), %	0.56***	−0.22**	ns	ns	ns	ns	0.27***	−0.18*	−0.34***
Micronaire	ns	0.22**	ns	ns	ns	ns	−0.26***	0.16*	ns
L(hvi), mm	−0.21**	−0.34***	ns	ns	ns	0.22**	0.27***	−0.24**	ns
Uniformity, %	−0.39***	ns	ns	ns	ns	ns	ns	ns	0.23**
Strength (hvi), kN m kg^{-1}	−0.36***	−0.19*	ns	ns	0.15*	ns	ns	−0.16*	0.18*
Elongation (hvi), %	−0.44***	−0.21**	ns	ns	0.20*	0.16*	ns	−0.18*	0.27**
Rd	0.21**	0.37***	0.19*	0.31***	ns	ns	−0.26***	0.42***	ns
+b	−0.51***	−0.21***	ns	ns	0.25***	0.18*	ns	−0.21**	0.26***

* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.001 level.
† L(w), fiber length by weight; SFC(w), short fiber content by weight; L(n), fiber length by number; SFC(n), short fiber content by number; D(n), diameter by number; IFF, immature fiber fraction; A(n), fiber cross-sectional area by number; FFF, fine-fiber fraction; stlmtr, stelometer; L(hvi), fiber length as determined by high-volume instrumentation; hvi, high-volume instrumentation; Rd, reflectance; +b, yellowness.
‡ OM, organic matter
§ CEC, cation exchange capacity.

were lower in the Carolina bay portion of the field where the soil moisture was greater and pH lower. It is possible that landscape position would provide an additional index of fiber yield and quality; however, these data were not available in this study. This effect may be addressed in future experiments.

Factor Analysis

Principle-component factor analysis was used in an attempt to group soil properties into common factors that could then be related to fiber properties. The soil properties from the 1996 and 1997 data sets were analyzed separately. Communalities estimate the portion of the variance in each model that was explained by the factor model (Brejda, 1998). The four factor models used in 1996 explained ≥90% of the variance for soil P, Na, Mg, organic matter, sand, and clay content (Table 8). The model explained ≥80% of the variance for soil moisture content, K, Ca, and soil pH. The variance explained for soil CEC and silt content was less satisfactory, with 66 and 52% explained, respectively. In 1997, a three-factor model was used to explain the variance in soil properties. The model explained ≥90% of the variance for soil P, soil Na, soil Mg, soil organic matter, and CEC. The model also explained ≥80% of the variance for soil moisture soil Ca and soil pH. The total variance explained for soil K was 78%.

An examination of the factor loadings from the 1996 and 1997 data set show two similar factors. The first factor in both years appears to be associated with the Carolina bay, with high positive loadings from soil P, soil organic matter, soil clay content (1996), and soil moisture (1997) and high negative loadings with soil pH and sand (1996). The second factor, in both years, appears to be associated with exchangeable bases as high loadings were obtained for soil K, Ca, Mg, and CEC. Soil silt content was also associated with this factor. A similar factor was described by Brejda (1998). The third factor was found to be associated with soil Na, and the fourth factor, which was necessary in 1996, was associated with soil moisture. An attempt was made to relate the extracted factor scores to fiber yield and quality through multiple regression analysis. This was unsuccessful and resulted in poor descriptions of both yield and quality parameters.

Table 8. Rotated factor loadings and communalities for soil properties for 1996 and 1997 cotton field experiment, Florence, SC.

	Factor loadings, 1996				
Property	1	2	3	4	Communalities
		1996			
Soil moisture, %	0.32	0.24	−0.06	0.82	0.84
P, mg kg^{-1}	0.96	−0.01	0.15	0.15	0.96
Na, mg kg^{-1}	0.14	0.23	0.93	−0.04	0.95
K, mg kg^{-1}	0.24	0.91	−0.03	0.09	0.89
Ca, mg kg^{-1}	−0.08	0.87	0.16	0.22	0.84
Mg, mg kg^{-1}	−0.28	0.86	0.24	0.15	0.91
Soil pH	−0.91	0.17	0.11	0.06	0.88
Organic matter, %	0.92	0.12	0.14	0.16	0.90
CEC†, cmol$_c$ kg^{-1}	0.42	0.60	−0.07	0.32	0.66
Sand, %	−0.91	−0.35	−0.08	−0.11	0.98
Silt, %	0.30	0.63	0.18	0.03	0.52
Clay, %	0.94	0.22	0.04	0.12	0.94
		1997			
Soil moisture, %	0.94	0.13	0.02		0.89
P, mg kg^{-1}	0.96	−0.16	0.09		0.95
Na, mg kg^{-1}	0.18	0.36	0.87		0.92
K, mg kg^{-1}	0.15	0.87	−0.08		0.78
Ca, mg kg^{-1}	−0.09	0.86	0.34		0.86
Mg, mg kg^{-1}	−0.30	0.86	0.29		0.92
Soil pH	−0.82	0.42	0.10		0.86
Organic matter, %	0.97	0.05	0.14		0.97
CEC, cmol$_c$ kg^{-1}	−0.11	0.94	0.29		0.97

† CEC, cation exchange capacity.

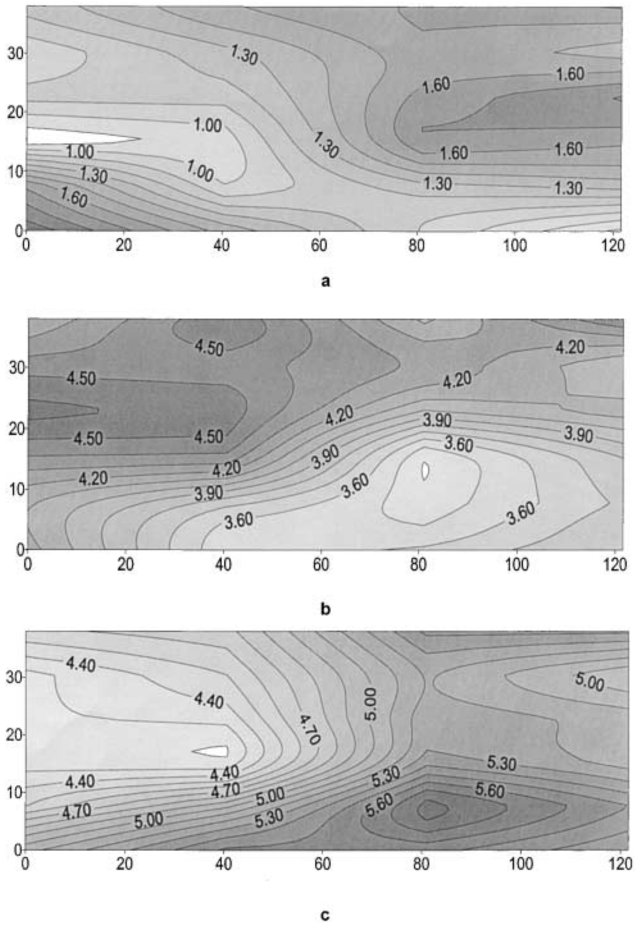

Fig. 3. Kriged contour plots of (a) cotton fiber yield (kg ha^{-1}) in 1997, (b) cotton micronAFIS in 1997, and (c) soil pH in 1997.

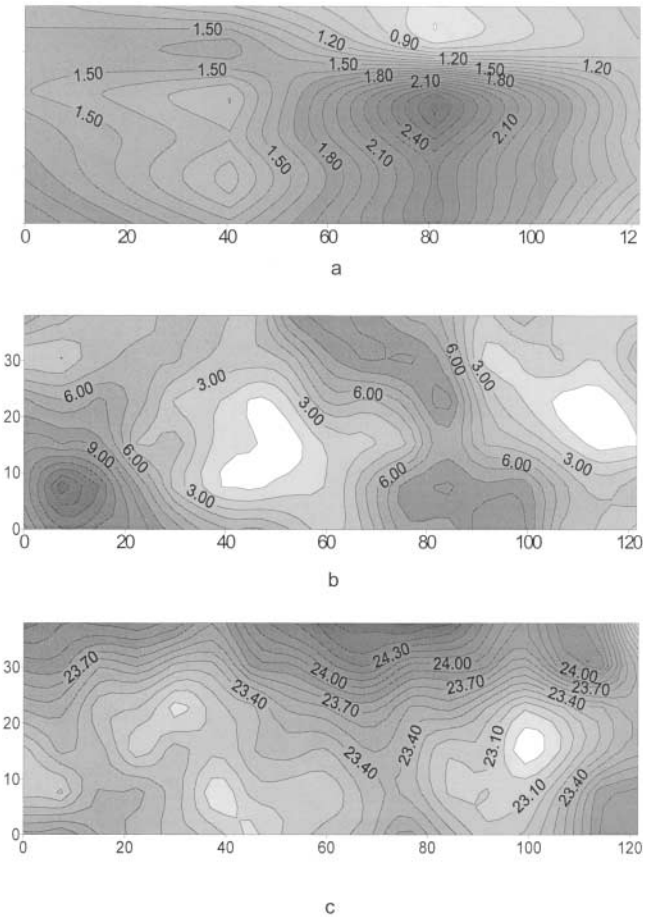

Fig. 4. Kriged contour plots of (a) soil cation exchange capacity (cmol$_c$ kg^{-1}) in 1996, (b) soil clay content in 1996, and (c) cotton fiber length by weight (mm) in 1996.

Soil and Fiber Maps

Selected soil, yield, and fiber property contour maps are presented in Fig. 3 and 4. The spatial distribution of soil pH, cotton yield, and cotton micronAFIS in 1997 are illustrated in Fig. 3. The Carolina bay present in the left of both maps contains the lowest soil pH and the lowest yield. The maps for soil CEC, clay content, and fiber length in 1996 are presented in Fig. 4. Additional fiber and soil maps could be useful in further study of the spatial relation between fiber quality and soil variability and, in the future, might be used to direct variable application systems.

Influence of Carolina Bay on Soil and Fiber Properties

Soil Properties

It is clear that the Carolina bay present in the experimental site represents a substantially different environment from that of the surrounding soils. In a closer investigation of the variations in the soil environment, all sample grid points were categorized as to their position, within or outside of the Carolina bay, for both years. The boundary of the Carolina bay was estimated by examining the kriged maps for soil organic matter and soil P for both years and comparing this to a map of the grid sampling points. The difference between these locations was then tested for significance by the Wilcoxon test, which evaluates sample medians, due to the unequal number of samples for each location (Table 9).

For the 1996 samples, significant differences were noted within and outside of the Carolina bay for all soil properties, with the exceptions of soil Ca, Mg, and clay content. Higher levels of soil P, Na, K, organic matter, and silt were found in the bay. In addition, soil moisture and CEC were greater within the bay. The soil pH and sand content were significantly lower (Table 9). In the 1997 samples, Ca, K, and CEC were not significantly different. The remaining soil properties, with the exception of soil pH, were at higher levels within the bay, compared with the soil outside.

Fiber Properties

In both the 1996 and 1997 growing seasons, cotton yields were significantly lower within the bay (Table 10). Significant differences were also found between the samples within and outside the bay for all AFIS fiber properties, with the exception of L(w) or L(n) in 1996. In the 1997 AFIS data, L(w), L(n), SFC(w), SFC(n), FFF, and perimeter were not significantly different for

Table 9. Influence of Carolina bay on soil properties for 1996 and 1997 cotton field experiment, Florence, SC.

	1996			1997		
Property	Bay mean† (median)	Mean out‡ (median)	Diff.§	Bay mean (median)	Mean out (median)	Diff.
Soil moisture, %	21.1 (20.7)	18.8 (18.3)	<0.0001	10.8 (10.4)	8.02 (7.94)	<0.0001
P, mg kg^{-1}	279.6 (269.7)	80.9 (80.0)	<0.0001	284.5 (279.2)	82.7 (78.7)	<0.0001
Na, mg kg^{-1}	6.5 (6.9)	5.54 (5.48)	0.0055	6.93 (6.59)	5.91 (5.50)	0.0062
K, mg kg^{-1}	152.8 (152.1)	136.5 (125.1)	0.0308	139.1 (140.0)	149.4 (141.1)	0.6495
Ca, mg kg^{-1}	221.2 (217.9)	214.8 (195.7)	0.4344	247.8 (239.3)	253.7 (251.1)	0.4840
Mg, mg kg^{-1}	47.5 (46.0)	50.7 (46.5)	0.7248	52.2 (46.4)	58.9 (53.2)	0.0667
Soil pH	4.78 (4.70)	5.48 (5.50)	<0.0001	4.54 (4.35)	5.30 (5.25)	<0.0001
Organic matter, %	1.36 (1.40)	0.54 (0.52)	<0.0001	1.32 (1.37)	0.49 (0.49)	<0.0001
CEC¶, cmol$_c$ kg^{-1}	1.78 (1.75)	1.47 (1.29)	0.0025	2.03 (2.00)	2.16 (2.05)	0.4831
Sand, %	57.4 (57.8)	80.9 (81.3)	<0.0001	–	–	–
Silt, %	36.6 (36.9)	14.3 (14.0)	<0.0001	–	–	–
Clay, %	5.95 (6.00)	4.74 (4.00)	0.1445	–	–	–

† Mean for Carolina bay ($n = 40$, 1996 and 1997).
‡ Mean excluding Carolina bay ($n = 62$, 1996 and 1997).
§ Test for difference between samples within and outside bay by Wilcoxon Two-Sample Test (t approximation, two-sided, $P > |z|$).
¶ CEC, cation exchange capacity.

Table 10. Influence of Carolina bay on fiber properties for 1996 and 1997 cotton field experiment, Florence, SC.

	1996			1997		
Property†	Bay mean‡ (median)	Mean out§ (median)	Diff.¶	Bay mean (median)	Mean out (median)	Diff.
Yield, kg ha^{-1}	478 (483)	1093 (1091)	<0.0001	607 (538)	785 (807)	0.0088
L(w), mm	0.92 (0.92)	0.93 (0.93)	0.1227	0.93 (0.93)	0.94 (0.94)	0.0983
SFC(w), %	8.43 (8.30)	9.11 (9.20)	0.0007	7.95 (7.95)	7.65 (7.60)	0.0885
L(n), mm	0.78 (0.78)	0.77 (0.77)	0.2342	0.79 (0.79)	0.80 (0.79)	0.0784
SFC(n), %	21.9 (21.9)	23.7 (23.8)	<0.0001	21.3 (21.4)	20.7 (20.8)	0.0546
D(n), μm	13.6 (13.6)	13.1 (13.2)	0.0002	13.8 (13.7)	13.4 (13.5)	0.0168
Theta	0.47 (0.48)	0.46 (0.46)	0.0003	0.49 (0.49)	0.47 (0.47)	0.0048
IFF, %	13.4 (12.9)	15.2 (15.1)	<0.0001	11.9 (11.9)	13.3 (13.1)	0.0137
A(n), μm^2	110.2 (110.1)	104.6 (104.8)	<0.0001	113.6 (113.3)	108.7 (108.7)	0.0087
FFF, %	16.7 (15.6)	19.1 (18.8)	0.0002	14.7 (14.6)	16.0 (15.6)	0.0856
MicronAFIS	3.99 (4.04)	3.66 (3.67)	<0.0001	4.26 (4.26)	3.92 (3.92)	0.0043
Perimeter, μm	54.1 (54.2)	53.7 (53.8)	0.0341	53.9 (53.9)	53.8 (53.7)	0.4509
Strength (stlmtr), kN m kg^{-1}	26.0 (26.2)	26.1 (26.1)	0.6919	22.4 (22.3)	22.8 (22.9)	0.1244
Elongation (stlmtr), %	7.29 (7.50)	7.40 (7.50)	0.3563	6.64 (6.60)	6.74 (6.70)	0.0075
Micronaire	3.90 (3.90)	3.77 (3.80)	0.1257	4.10 (4.00)	3.87 (3.90)	0.0383
L(hvi), mm	1.09 (1.10)	1.12 (1.12)	0.0001	1.12 (1.13)	1.13 (1.13)	0.2183
Uniformity, %	82.1 (81.9)	82.1 (82.2)	0.9963	82.3 (83.3)	83.5 (83.6)	0.0757
Strength (hvi), kN m kg^{-1}	28.4 (28.8)	28.5 (28.4)	0.9814	29.1 (29.3)	29.4 (30.1)	0.0709
Elongation (hvi), %	6.28 (6.30)	6.26 (6.30)	0.9623	6.47 (6.50)	6.63 (6.60)	0.0674
Reflectance, Rd	78.2 (78.6)	76.3 (76.6)	<0.0001	76.8 (77.0)	76.4 (76.4)	0.0519
Yellowness, +b	8.80 (8.85)	8.85 (8.80)	0.7472	9.21 (9.15)	9.77 (9.80)	<0.0001

† L(w), fiber length by weight; SFC(w), short fiber content by weight; L(n), fiber length by number; SFC(n), short fiber content by number; D(n), diameter by number; IFF, immature fiber fraction; A(n), fiber cross-sectional area by number; FFF, fine-fiber fraction; stlmtr, stelometer; L(hvi), fiber length as determined by high-volume instrumentation; hvi, high-volume instrumentation.
‡ Mean for Carolina bay [$n = 38$, 28 for Advanced Fiber Information System (AFIS), high-volume instrumentation (HVI) 1996; $n = 40$, 28 for AFIS, HVI, 1997].
§ Mean excluding Carolina bay ($n = 62$, 57 for AFIS, HVI 1996; $n = 61$, 51 for AFIS, HVI, 1997).
¶ Test for difference between samples within and outside bay by Wilcoxon Two-Sample Test (t approximation, two-sided, $P > |z|$).

samples from within and outside the bay. The higher levels of micronAFIS, diameter, and area are of particular interest, however. Fiber strength (by stelometer or HVI) was not different in 1996 and 1997, and elongation percentage was significantly different only as measured by stelometer in the 1997 growing season. Micronaire was found to be significantly higher in the bay in 1997 but not in 1996 (although a similar trend was apparent). Finally, fiber Rd was significantly higher within the bay in both years, and fiber +b was lower (significantly so in 1997). Taken collectively, these data indicate that the fiber from the Carolina bay was more mature (higher micronAFIS and micronaire and lower IFF) but shorter and thicker (lower length and higher diameter and area). The fiber was also whiter (higher Rd) and tended to be less yellow (lower +b). These differences in soil and fiber properties would suggest that separate soil and fiber management strategy should be employed to manage cotton grown in fields containing Carolina bay formations. It is possible that fertility requirements within the Carolina bay may not be as high as those areas outside of the bay. Variable rate fertilizer application may offer an attractive alternative in these situations. It is also possible that selective harvest and segregation of the fiber within the Carolina bay may maximize the fiber quality and return from the crop.

SUMMARY AND CONCLUSIONS

Variations in cotton fiber yield and quality were studied in a production environment in South Carolina. The majority of the soil properties measured exhibited skewed distributions with slight, but significant, kurtosis values. All soil properties were not normally distributed.

The CVs ranged from approximately 10% for soil pH to almost 75% for soil P in both years of the study. Fiber yield samples exhibited only slight skewness and kurtosis and possessed normal distributions; however, variability was considerable, with CVs of 42 and 53% for 1996 and 1997, respectively. The majority of fiber quality properties were normally distributed, with small skewness and kurtosis values. Exceptions were noted for elongation by stelometer and HVI in both years, FFF and +b in 1996, and L(n), L(hvi), uniformity, and Rd in 1997. The AFIS maturity index FFF had the greatest coefficient of variability in both 1996 and 1997 (20.1 and 21%, respectively). The other AFIS maturity indices and HVI micronaire also exhibited substantial variability.

All soil properties investigated displayed spatial correlation, with the exception of soil moisture in 1996. The range of spatial correlation varied from 33 to 99 m. The soil properties with the greatest range included soil pH, Na, P, and organic matter. Soil Ca, Mg, and K exhibited the least variability. Fiber yield displayed spatial correlation in 1997 only. Fiber properties that consistently displayed spatial correlation included the AFIS maturity and shape properties, fiber micronaire, and fiber length.

Correlation analysis was performed in further investigations of the relation between soil and fiber properties. Soil pH, soil P, and soil organic matter were all found to be correlated with fiber yield and with a number of fiber properties, including AFIS shape and maturity indices, micronaire, length, and HVI color indices. Further research is necessary to determine the influence of landscape position. Factor analysis of soil properties identified four factors in 1996 and three in 1997. In both years, a *Carolina bay* factor and an *exchangeable bases* factor were obtained; however, these factors were not successfully related to fiber yield and quality. Finally, significant differences were observed among soil, fiber yield, and fiber quality properties sampled from within and outside of the Carolina bay formation.

It is clear from our results that there is a relation, spatial and nonspatial, between soil and fiber variation from the South Carolina Coastal Plain site that was studied. The degree of variability observed suggests that precision agriculture techniques could provide effective management strategies for maximizing fiber yield *and* quality. Possible techniques would include variable-rate fertilizer application and selective harvest. Influences of soil properties and soil type on fiber quality should be considered when developing a cotton soil management plan, particularly when a Carolina bay or similar landform is present in the production field. Research currently underway is investigating further implications of these relations.

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